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EPIC-2 CALCULATED IMPACT LOADING HISTORIES OF THIN PLATES

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U.S. ARMY LABORATORY COMMAND

BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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Although the EPIC-2 code can predict the ballistic shock environments in projectile-impacted targets, these targets must be axisymmetric. By modifying the code to calculate the history of an impacting projectile on the target, one can use the loading history as input for a finite element analysis of the ballistic shock in non-axisymmetric targets. Loading histories of 20 mm fragment simulator projectiles for impact velocities of 366 m/s and 1012m/s on 38 mm x 914 mm circular rolled homogeneous armor plates have been calculated by the EPIC-2 code and have been used in ADINA finite element structural response analyses of the plate. Comparisons of EPIC-2 and ADINA responses calculations show that the EPIC-2 code can be used to calculate loading histories which do represent the loading of a target by nonperforating projectiles.

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I. INTRODUCTION

A series of nonperforating ballistic impact experiments[1] were conducted by the US Army Combat Systems Testing Agency (USACSTA) to characterize the ballistic shock environment in rolled homogeneous armor (rha) targets. Two of these experiments involved the normal impact of 20 mm fragment simulator projectiles (fsp) on 914 mm x 914 mm x 38 mm rha plates at impact velocities of 366 m/s and 1012 m/s. Normal displacements were measured at radial distances of 105 mm and 241 mm from the center of the plates,and radial strains were measured at radial distances of 100 mm, 170 mm and 240 mm from the center of the plates. The EPIC-2 hydro-code[2] was used by the US Army Ballistic Research Laboratory to model these experiments and to calculate the plate's responses to impact of the fsp. Comparison[3] of the measured and EPIC-2 calculated responses (normal displacement and radial strain) showed that the EPIC-2 could calculate the ballistic shock environments in projectile-impacted targets within the limitations of the code.

EPIC-2 is an axisymmetric code; therefore, it is limited to axisymmetric targets and to normal impacting projectiles. If, however, the EPIC-2 code is modified to calculate the projectile loading history of the target, this loading history can be used as input for a finite element analysis of ballistic shock in non-axisymmetric targets. This report describes the EPIC-2 calculated loading histories of a 20 mm fsp with impact velocities of 366 m/s and 1012 m/s on a 38 mm thick rha plate, the application of these loading histories in an ADINA[4] finite element structural response analyses of the plates, and the results of the comparison of the EPIC-2 and ADINA calculations.

II. EPIC-2 CODE AND CALCULATED LOADING HISTORIES

The major characteristics of the EPIC-2 code are listed in Table 1. The code performs elastic-plastic impact computations in two dimensions for axisymmetric and plane strain problems with either free or fixed boundaries. It is based on a Lagrangian finite element and lumped mass formulation in which the equations of motion are integrated directly. Nonlinear material strength and compressibility effects are included to account for elastic-plastic flow and wave propagation. The code has material descriptions for strain hardening, strain rate effects, thermal softening and failure. It uses a constant strain, triangular finite element which is well suited to represent the severe distortions occurring during high velocity impact.

The use of an axisymmetric code to model the USACSTA experiments was justified since the impact point in the experiments was the center of the plate. The plate's response for a brief period of time after impact would be axisymmetric and independent of the plate's geometry and edge boundary conditions. The calculated times for the dilatation and shear waves to travel the shortest round trip distance between the impact point and the plate's edges were 157 μs and 285 μs, respectively. Plate displacements, velocities, accelerations and strains were calculated for the first 300 μs after impact. Comparison of calculated displacements at a point 244 mm out from the impact point for free and fixed edges showed identical plate responses for times less than 215 μs. Comparison of calculated radial strains at the 240 mm location showed identical response for times less than 125 μs and minor differences in the response for times greater than 125 μs.

Table 1. EPIC-2 Code Characteristics	
DISCRETIZATION:	FINITE ELEMENT METHOD • 2D constant strain triangles • Lumped mass formulation
MESH DESCRIPTION:	LAGRANGIAN
MATERIAL MODEL:	CONSTITUTIVE MODEL • Incremental elastic-plastic • Von Mises yield criterion • Compressibility effects • Strain rate effects • Strain hardening • Thermal softening EQUATION OF STATE • Mie-Gruneisen
FAILURE CRITERIA:	VOLUMETRIC STRAIN EFFECTIVE PLASTIC STRAIN
POST-FAILURE MODELS:	PRESSURE CUTOFF SHEAR AND TENSION FAILURE TOTAL FAILURE

Two of the variables calculated by the EPIC-2 code for each computational time interval were the total linear momentum of the projectile and of the plate. The code was modified to calculate the loading history of the projectile on the plate by calculating the time rate-of-change in the plate's total linear momentum over each computational time interval. Although the computational time interval for these two impact velocities was in the order of 0.05 μs, the loading was printed out at 1.0 μs intervals.

Figures 1 and 2 show the computed loading history of the plate for impact velocities of 366 m/s and 1012 m/s. In both cases the loading time is less than 50 μs.

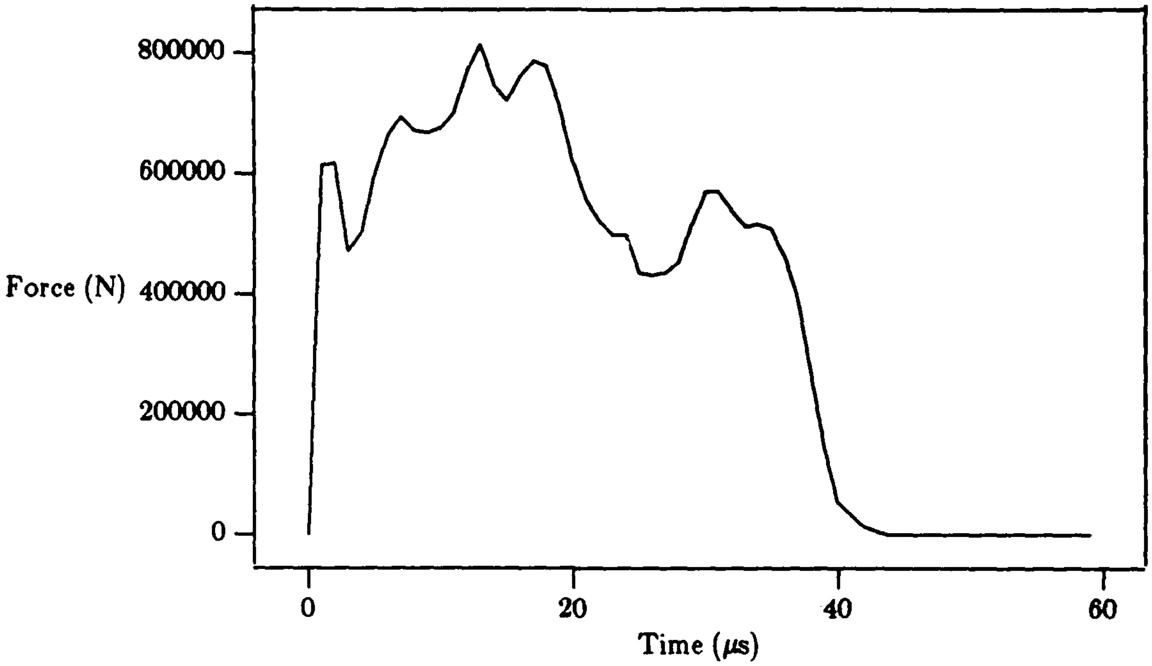

Figure 1. EPIC-2 calculated impact loading history for $v_p = 366$ m/s.

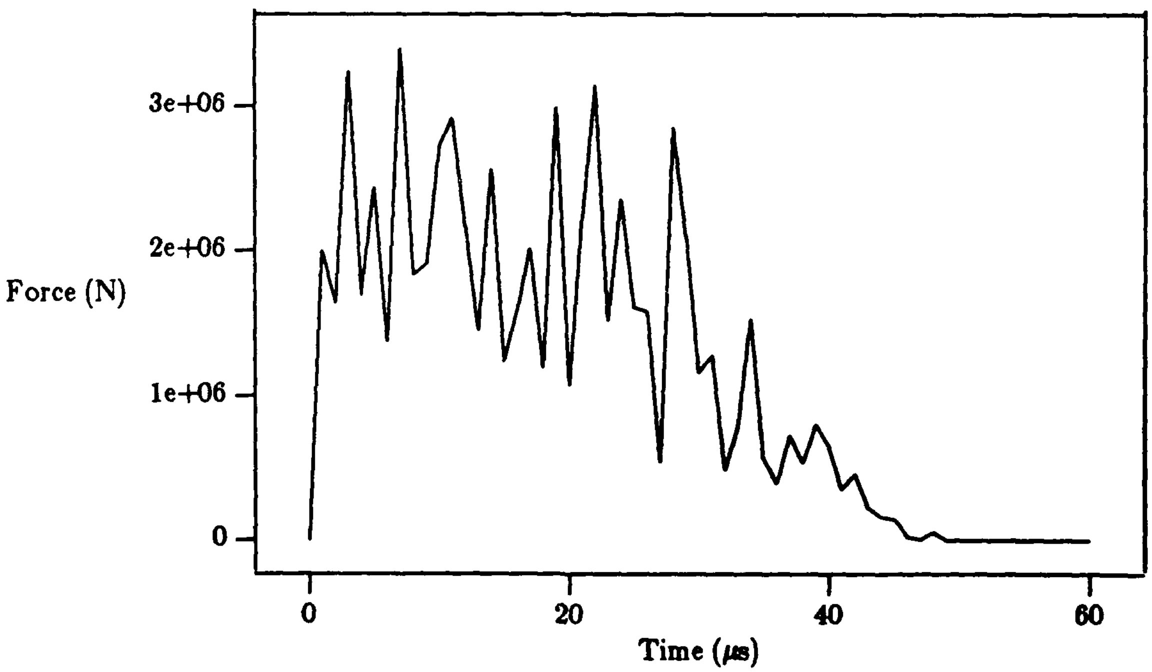

Figure 2. EPIC-2 calculated impact loading history for $v_p = 1012$ m/s.

III. ADINA CALCULATIONS AND EPIC-2 COMPARISONS

The ADINA finite element model of the plate is shown in Figure 3 and it is identical to the EPIC-2 model. The plate is modeled as a circular one, 914 mm in diameter and with free boundaries, and it consists of 671 nodes and 1200 triangular elements. Both the horizontal and the vertical distances between the nodes are 7.62 mm. Only the first 100 mm of the plate's 457 mm radius is shown. Loading is applied to the top first three radial nodes as shown in Figure 3. (Recovery of the 20 mm fsp after the experiments showed the contact surface of the projectile mushroomed from a 20 mm diameter to a 33 mm diameter.)

The analysis is nonlinear, small deflection and small strain. The time integration scheme used is the Newmark method with a time step increment of 1 μs, and the equilibrium iteration method used is the full Newton without line search. The material model of the plate is bilinear elastic-plastic in which Young's modulus $E = 145.1$ GPa, Poisson's ratio $\nu = 0.275$, yield stress $\sigma_Y = 916.2$ MPa, and strain hardening modulus $E_T = 510.1$ MPa; and the density of the plate is 7876 kg/m^3. The same material properties are used in the EPIC-2 calculations.

Figure 4 through 10 are plots of both the ADINA and EPIC-2 calculated responses at the same locations on the back of the plate for the 366 m/s impact velocity loading history. Figures 4 and 5 show excellent agreement of two calculated normal displacements at the 106 mm and 244 mm locations. Figures 6 and 7 show good agreement of the radial strains at the 100 mm and 170 mm locations and Figure 8 shows excellent agreement of the radial strains at the 240 mm location. Figures 9 and 10 show fair agreement of the normal accelerations at the 106 mm and 244 mm locations. For times greater than 75 μs, the ADINA peak accelerations are greater than the EPIC-2 peak accelerations at the 106 mm location. This is also the case for times greater than 100 μs at the 244 mm location. Figures 11 and 12 show the ADINA and EPIC-2 primary shock spectra obtained from the normal acceleration histories shown in Figures 9 and 10. A recursive filter technique[5] is used to obtain these spectra. The agreement of the spectra is excellent from 500 to 70000 Hz at both locations on the back of the plate and poor for frequencies greater than 70 kHz. For frequencies greater than 70 kHz, the ADINA spectrum is greater in magnitude than the EPIC-2 spectrum.

Figures 13 through 19 are plots of both ADINA and EPIC-2 calculated responses at the same locations on the back of the plate for the 1012 m/s impact velocity loading history. Figure 13 shows excellent agreement between the the normal displacements at the 107 mm location for time less than 100 μs and only fair agreement for times greater than 100 μs. Figure 14 shows good agreement of the normal displacements at the 244 mm location. The ADINA maximum negative and positive peak displacements in this figure are approximately 10 percent greater than the EPIC-2 peak displacements and the ADINA peaks occur at a slightly later time. Figures 15 through 17 show good agreements of the radial strains at the 100 mm, 170 mm and 240 mm locations. These three figures also show that the ADINA curves lag behind the EPIC-2 curves. This lagging is noticeable also in figure 14. A possible explanation for this lagging is the time integration scheme used by the two codes. The ADINA analyses use an implicit scheme whereas the EPIC-2 analyses use an explicit scheme. Figures 18 and 19 show fair agreement of the normal accelerations at the 106 mm and 244 mm locations. The EPIC-2 peak accelerations are greater than the ADINA peak accelerations for earlier times whereas the opposite is true for later times. It appears that the EPIC-2 accelerations are damping out and that the ADINA accelerations are not. Figures 20 and 21 show excellent agreement of the ADINA and EPIC-2 calculated primary shock spectra between 500 and 20000 Hz and poor agreement for frequencies greater than 20 khz.

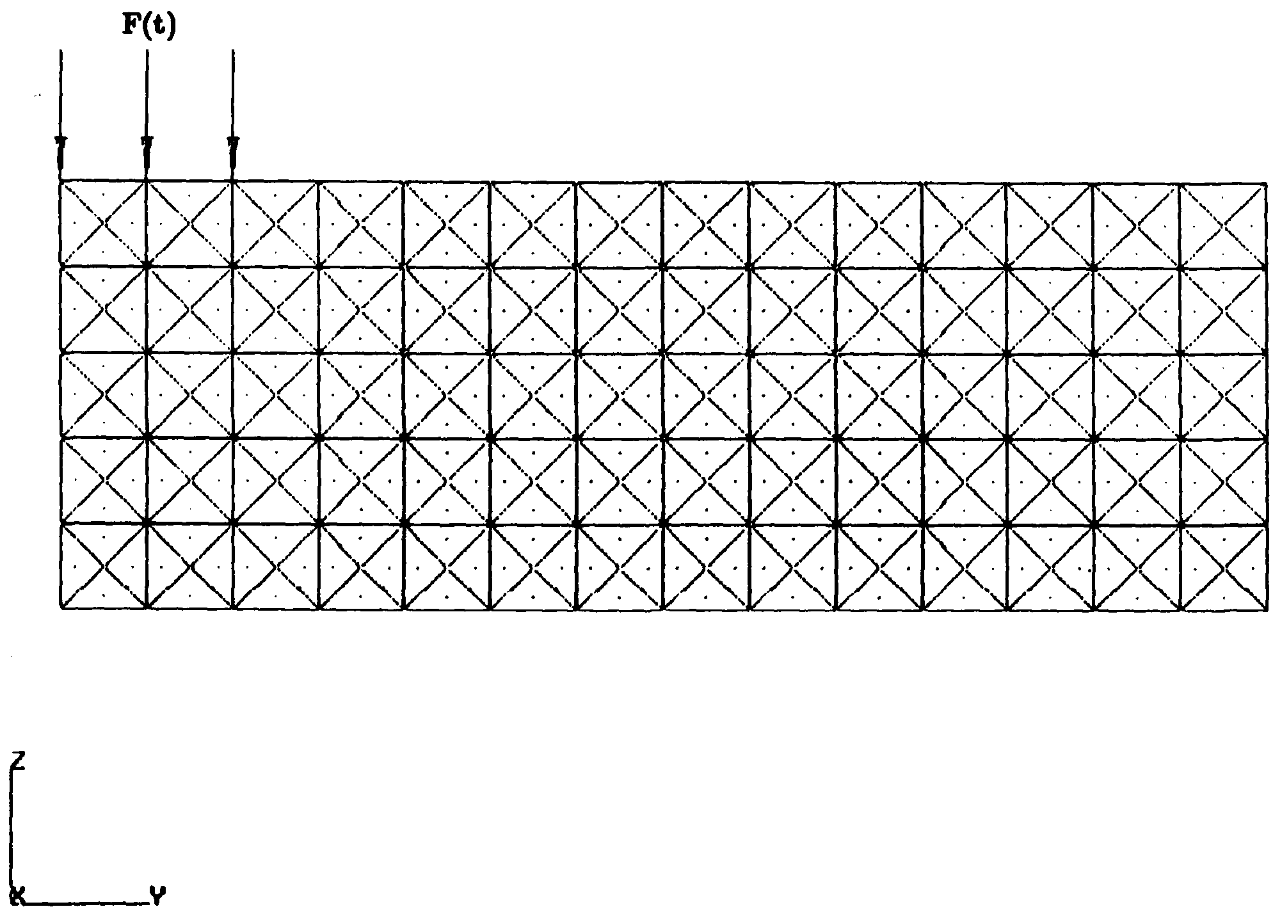

Figure 3. ADINA finite element model of 38 mm thick plate.

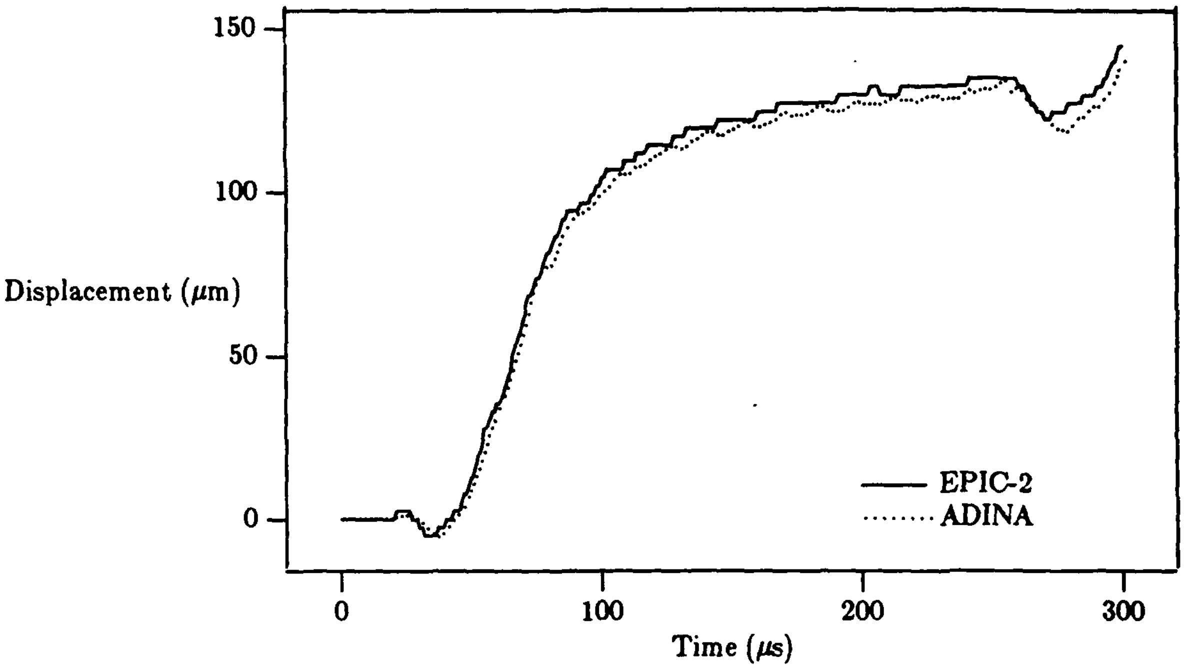

Figure 4. EPIC-2 and ADINA normal displacement histories at 106 mm for $v_p = 366$ m/s.

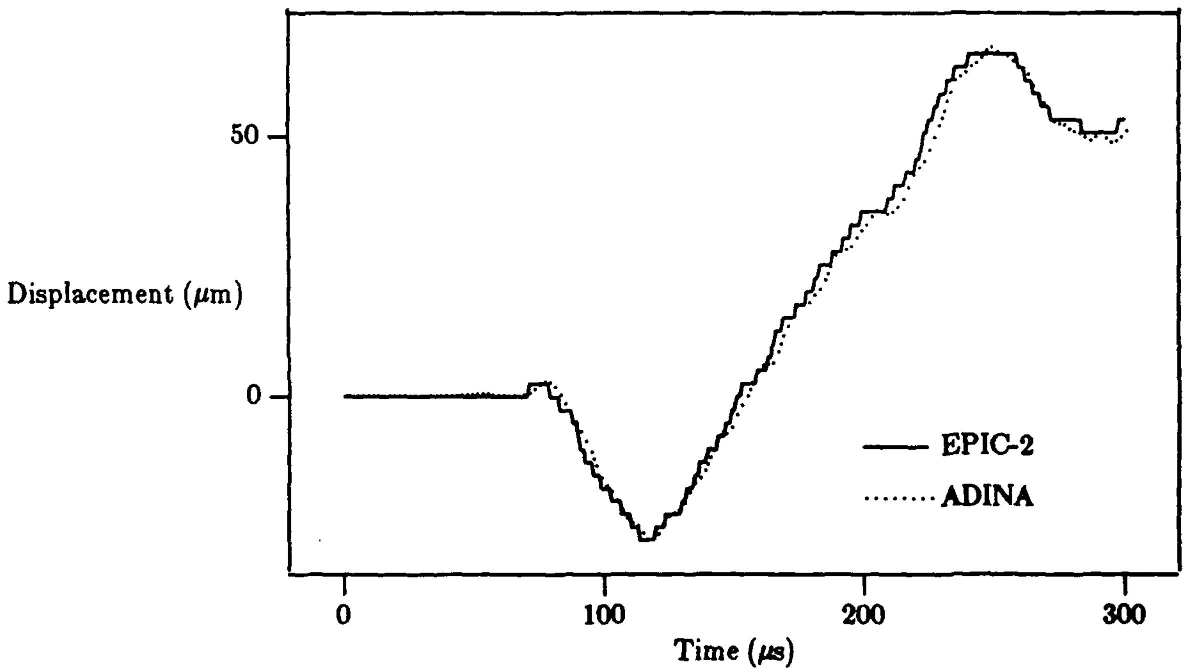

Figure 5. EPIC-2 and ADINA normal displacement histories at 244 mm for $v_p = 366$ m/s.

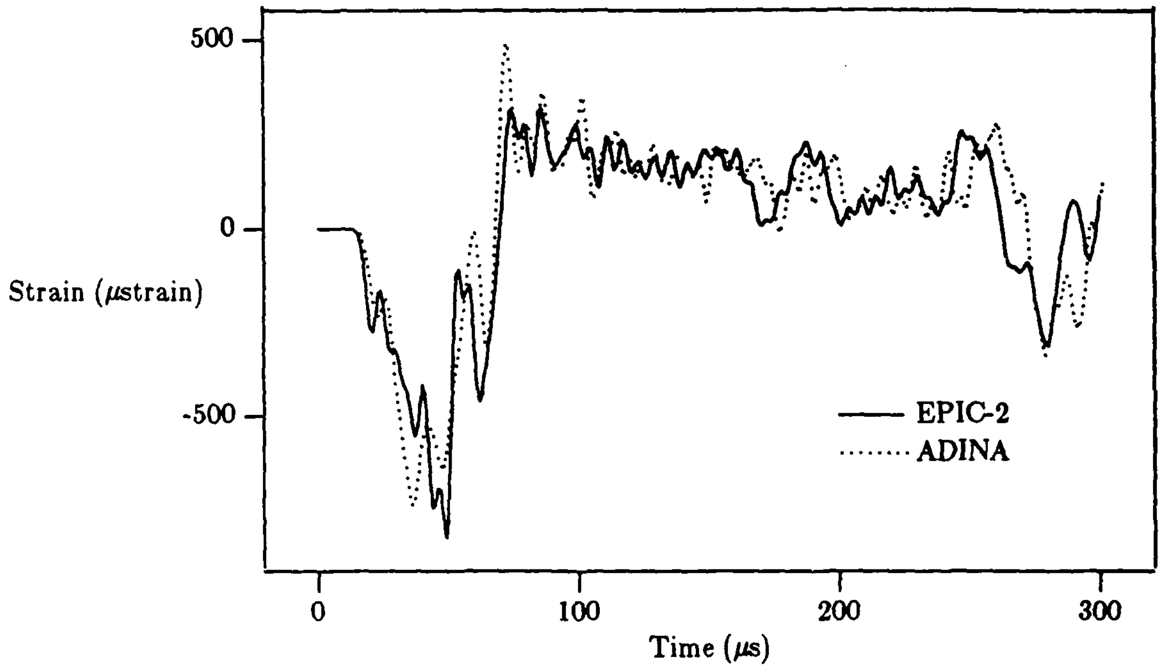

Figure 6. EPIC-2 and ADINA radial strain histories at 100 mm for $v_p = 366$ m/s.

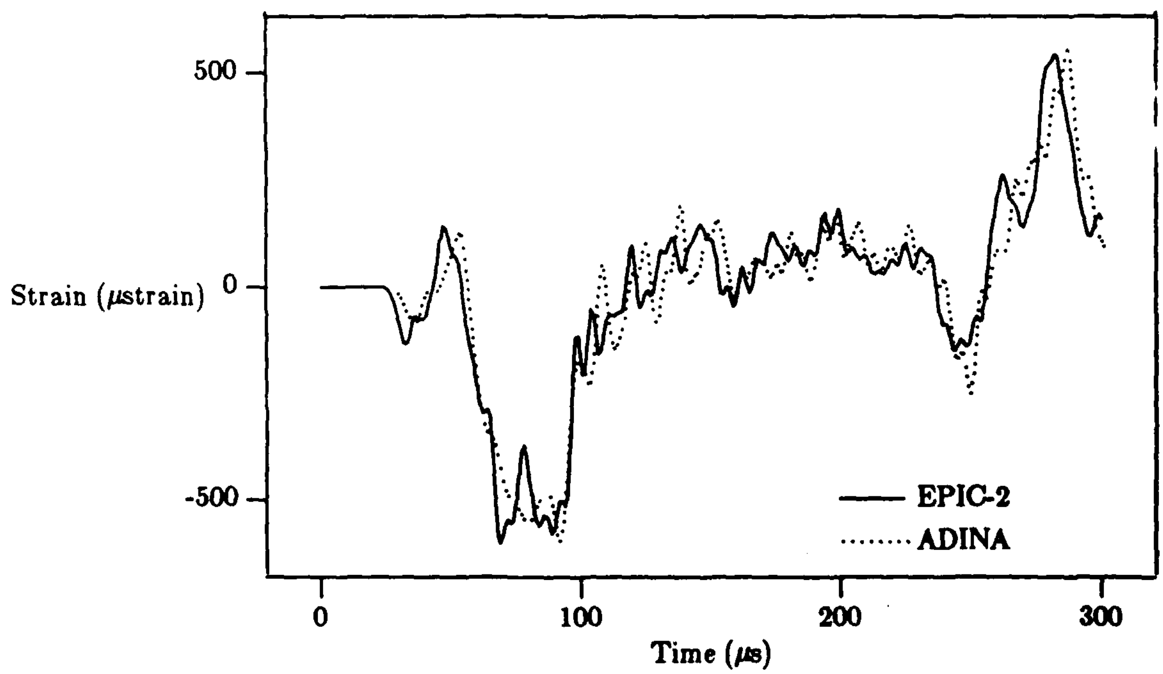

Figure 7. EPIC-2 and ADINA radial strain histories at 170 mm for $v_p = 366$ m/s.

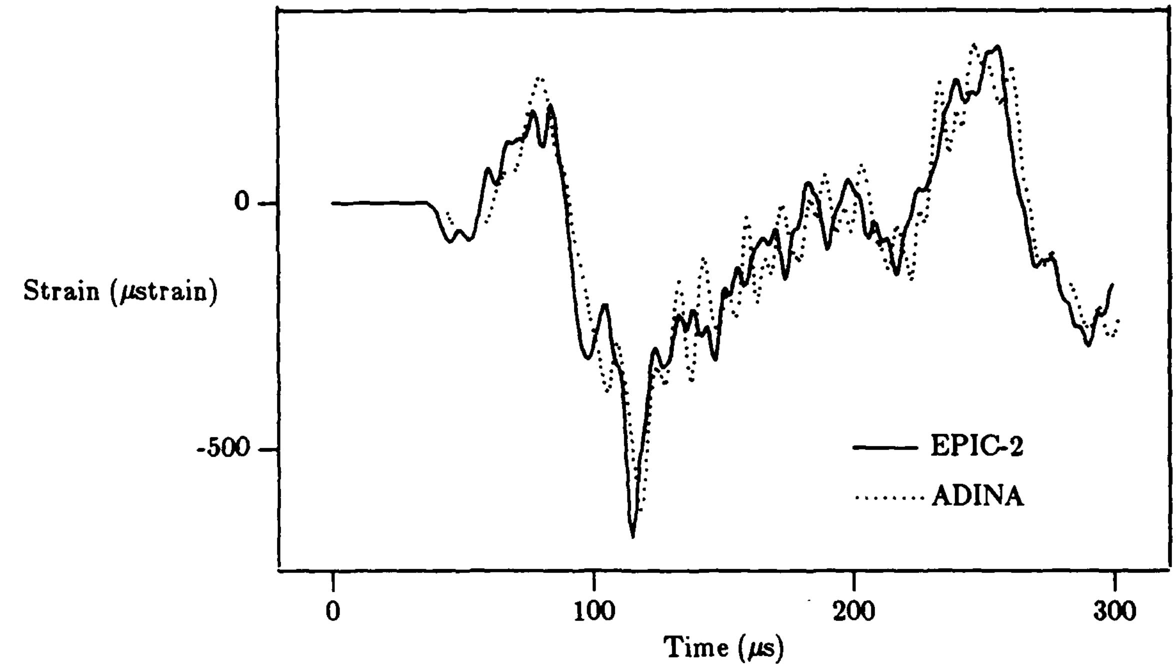

Figure 8. EPIC-2 and ADINA radial strain histories at 240 mm for $v_p = 366$ m/s.

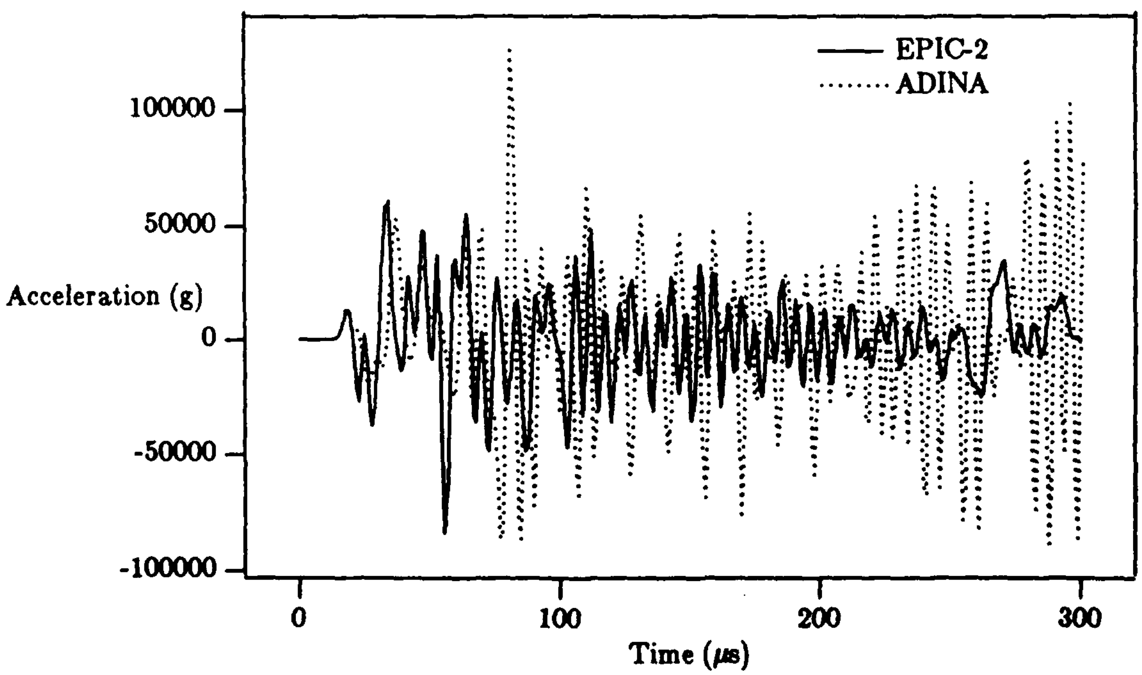

Figure 9. EPIC-2 and ADINA normal acceleration histories at 106 mm for $v_p = 366$ m/s.

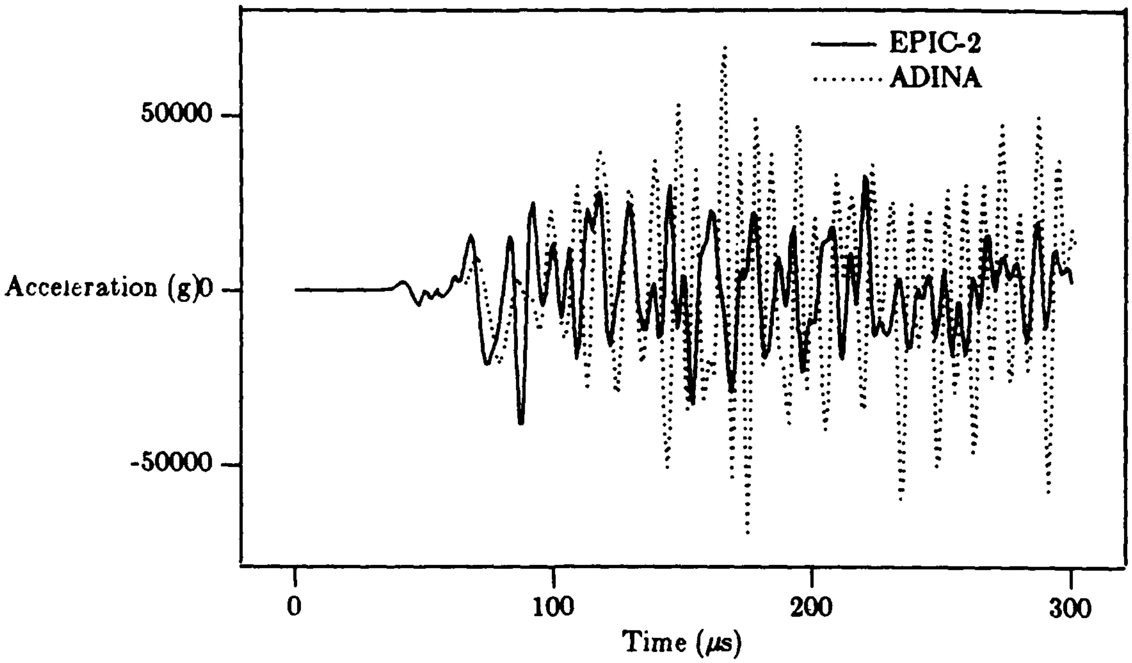

Figure 10. EPIC-2 and ADINA normal acceleration histories at 244 mm for $v_p = 366$ m/s.

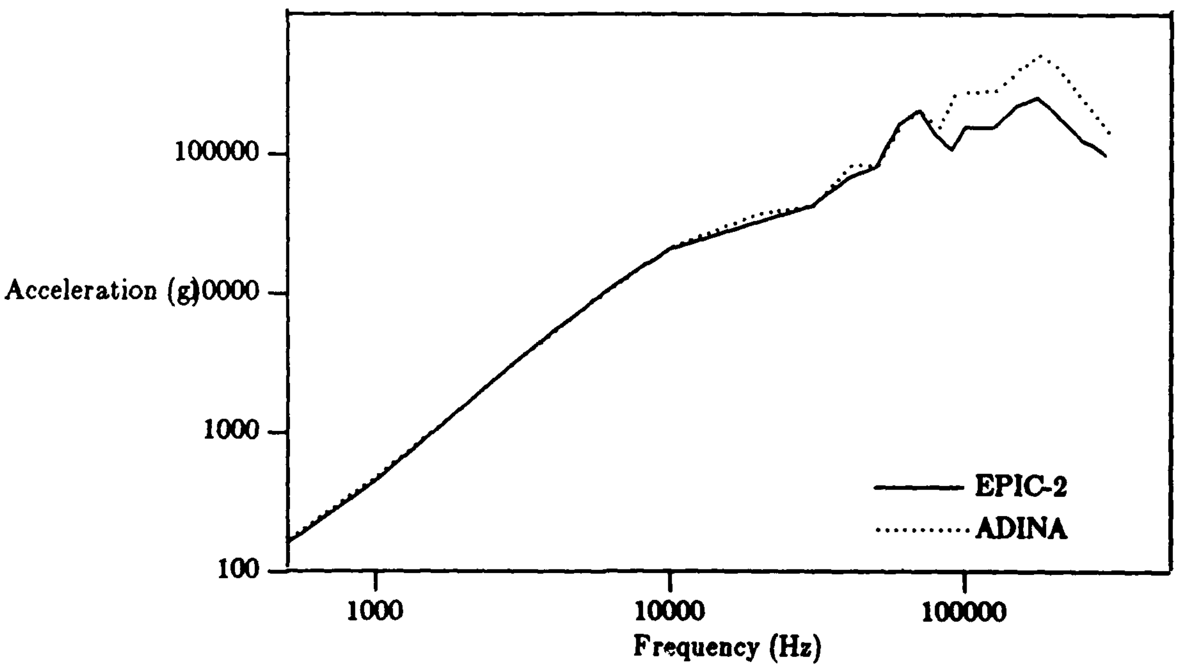

Figure 11. EPIC-2 and ADINA primary shock spectra at 106 mm for $v_p = 366$ m/s.

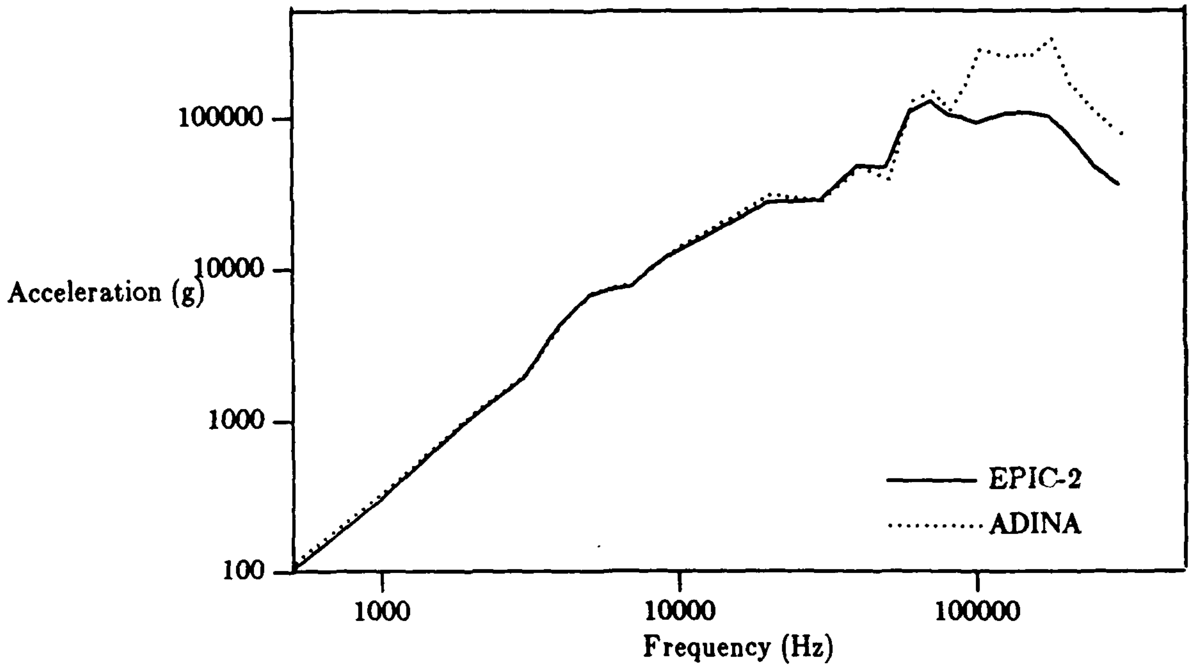

Figure 12. EPIC-2 and ADINA primary shock spectra at 244 mm for $v_p = 366$ m/s.

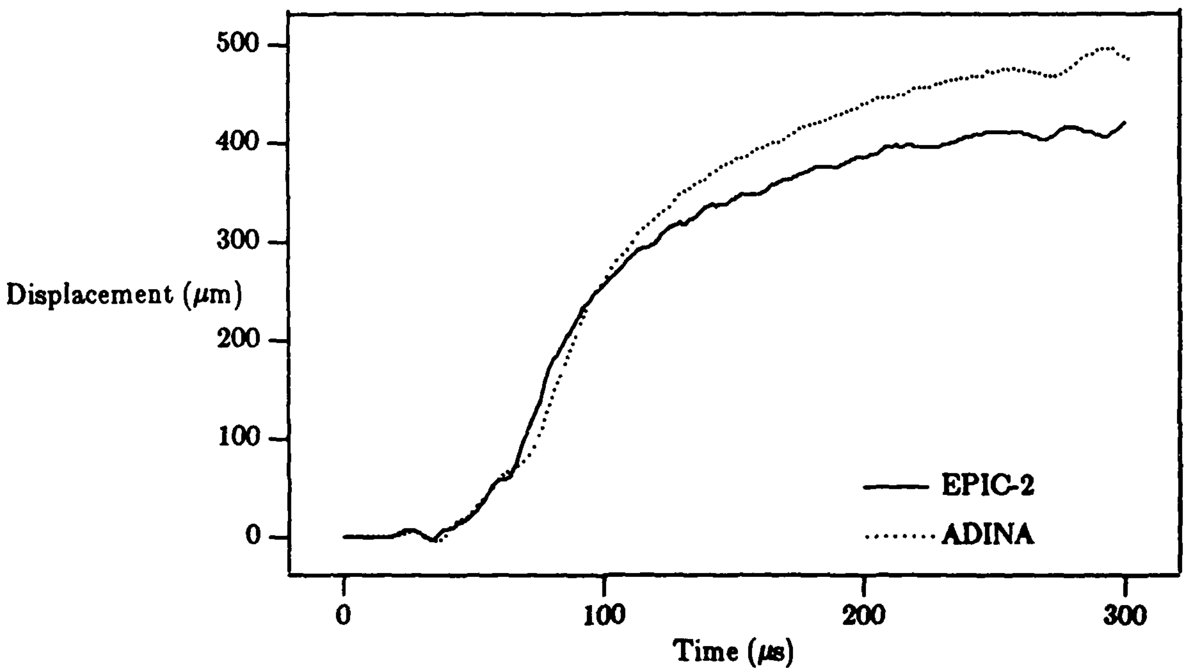

Figure 13. EPIC-2 and ADINA normal displacements histories at 106 mm for $v_p = 1012$ m/s.

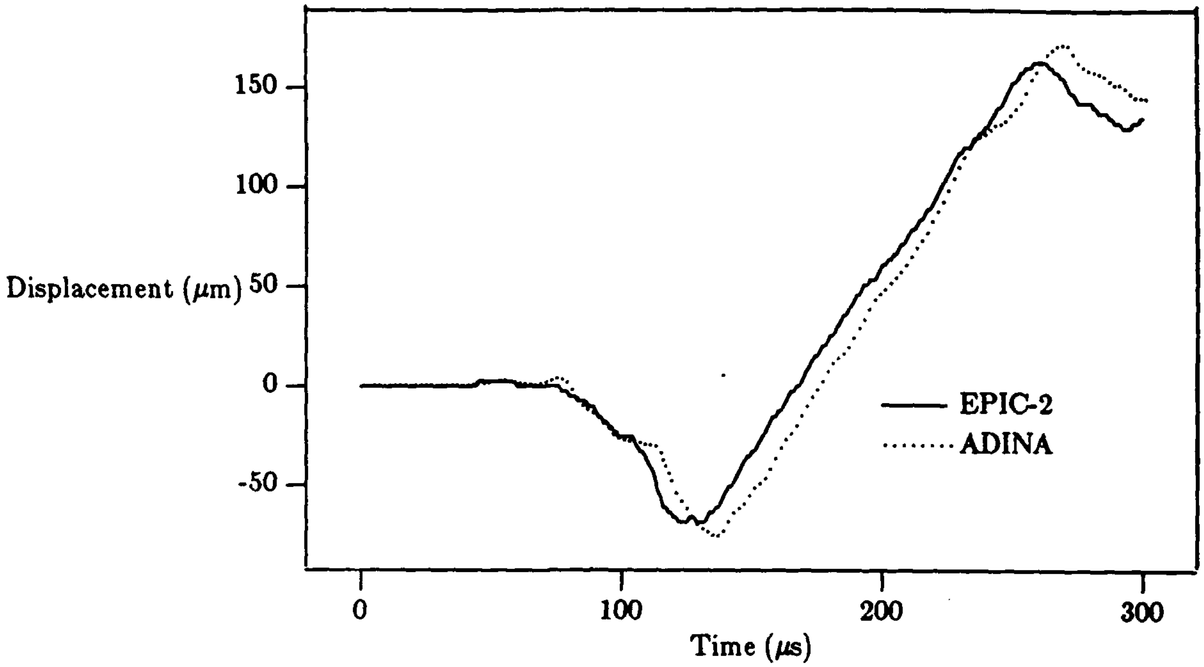

Figure 14. EPIC-2 and ADINA normal displacements histories at 244 mm for $v_p = 1012$ m/s.

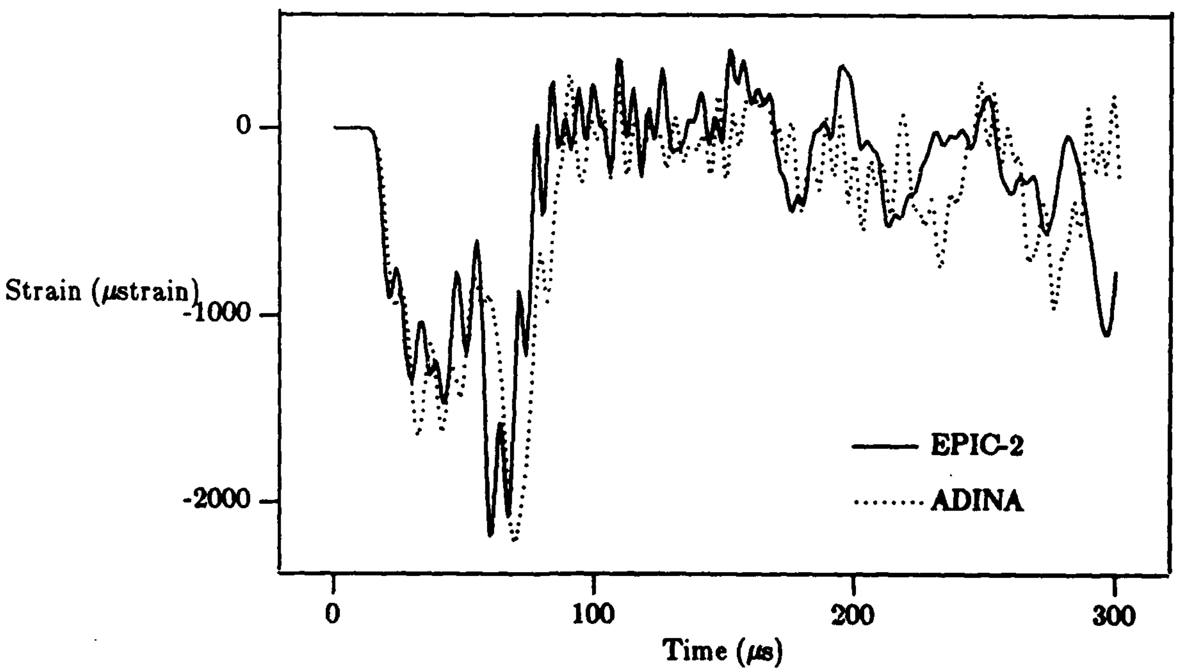

Figure 15. EPIC-2 and ADINA radial strain histories at 100 mm for $v_p = 1012$ m/s.

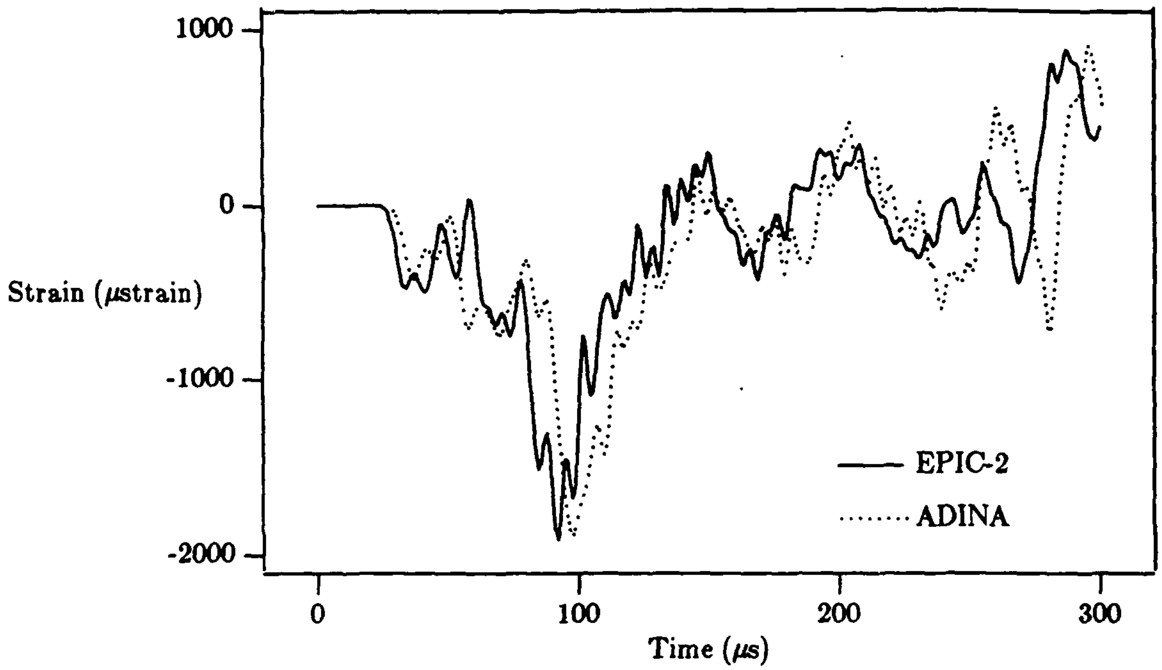

Figure 16. EPIC-2 and ADINA radial strain histories at 170 mm for $v_p = 1012$ m/s.

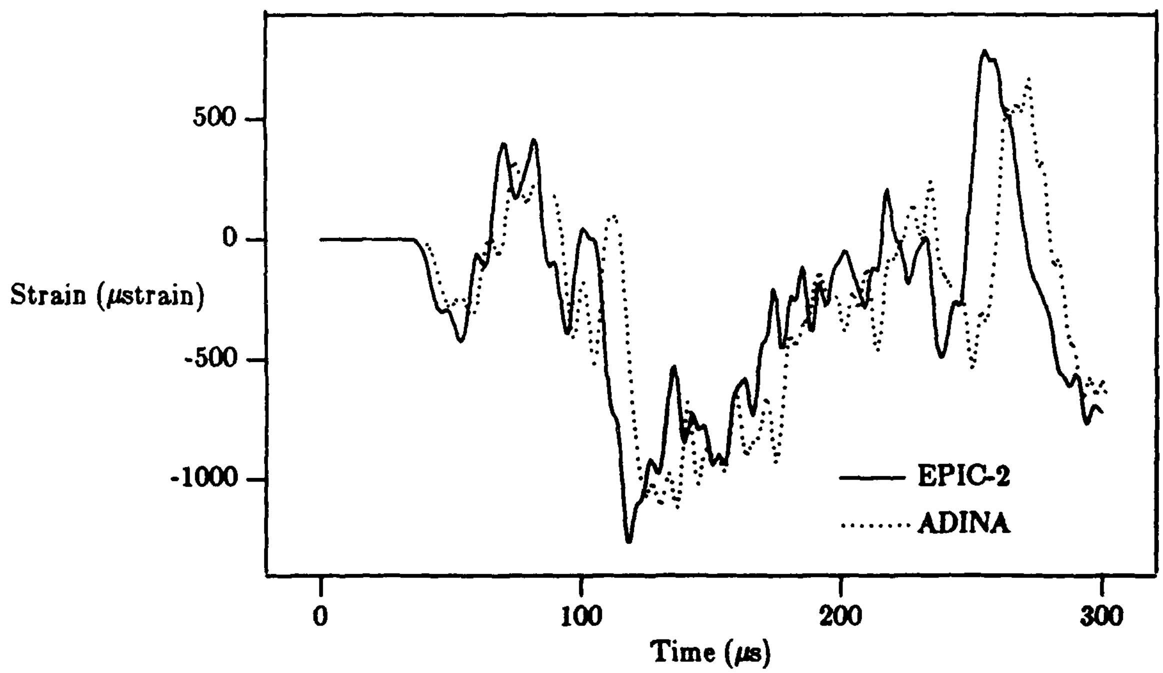

Figure 17. EPIC-2 and ADINA radial strain histories at 240 mm for $v_p = 1012$ m/s.

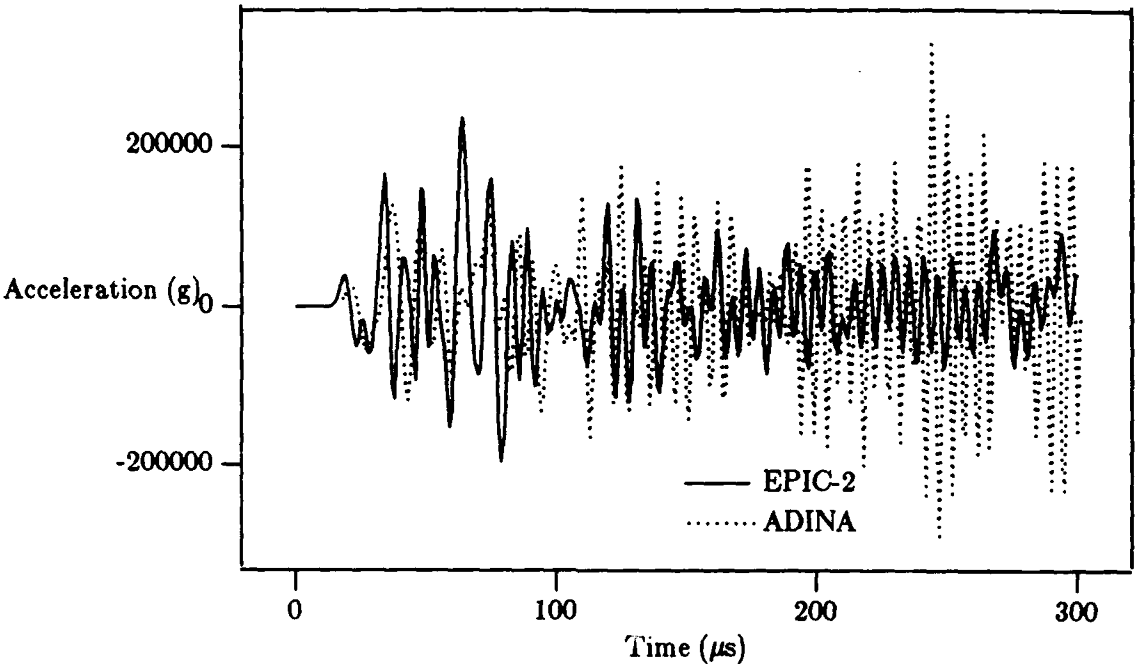

Figure 18. EPIC-2 and ADINA normal acceleration histories at 106 mm for v_p = 1012 m/s.

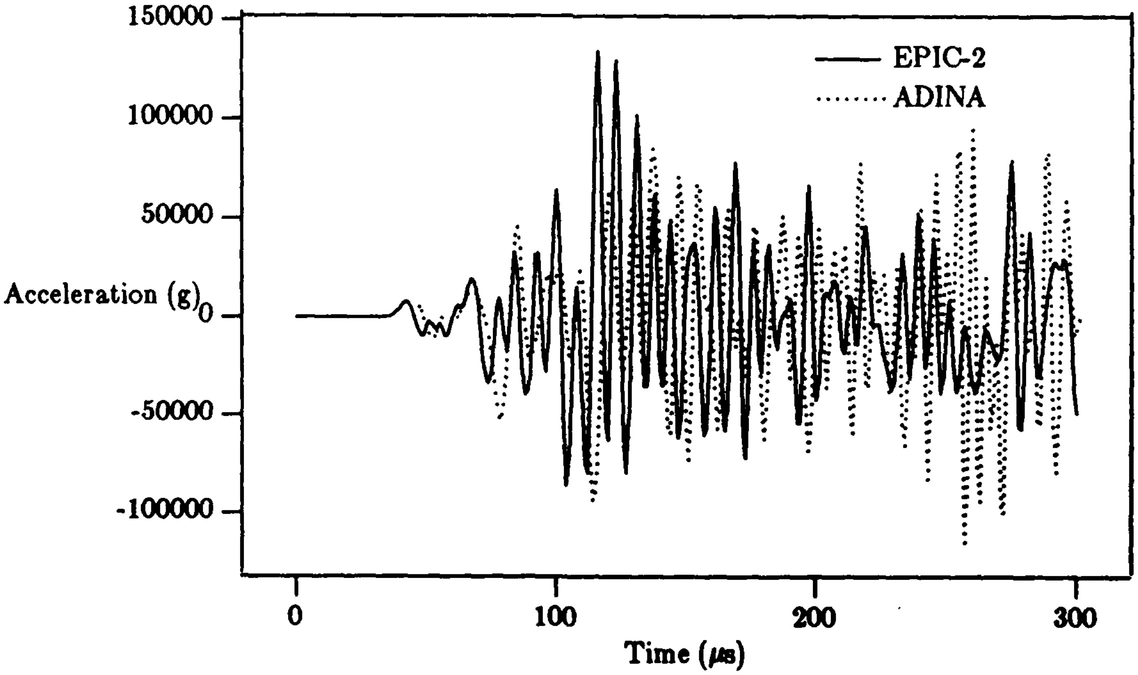

Figure 19. EPIC-2 and ADINA normal acceleration histories at 244 mm for v_p = 1012 m/s.

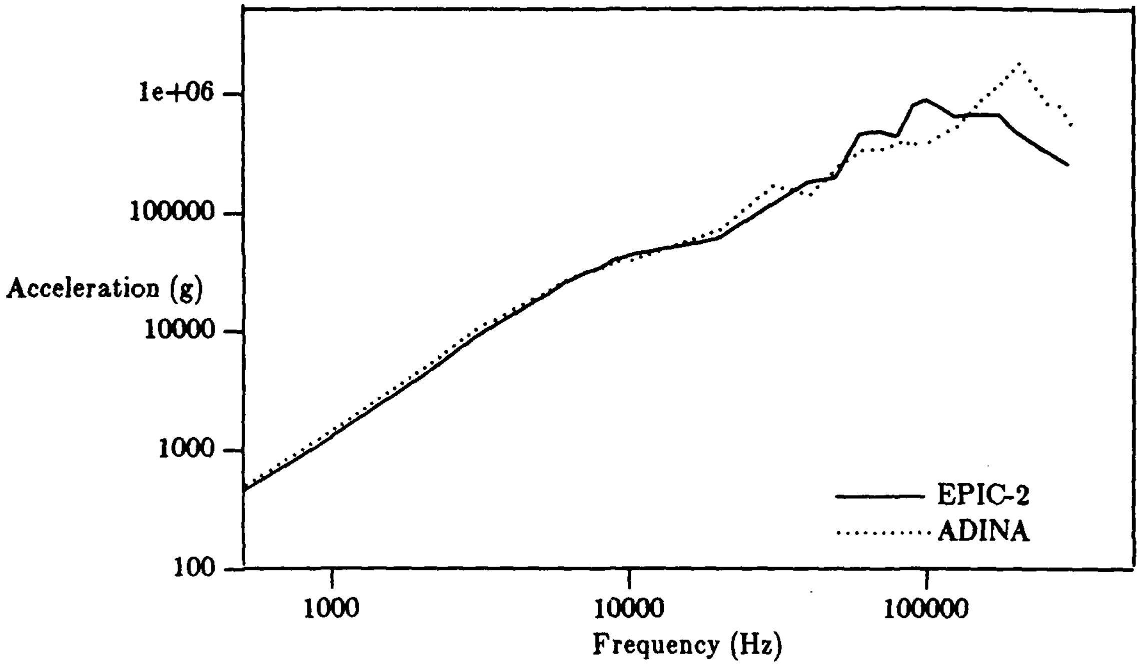

Figure 20. EPIC-2 and ADINA primary shock spectra at 106 mm for $v_p = 1012$ m/s.

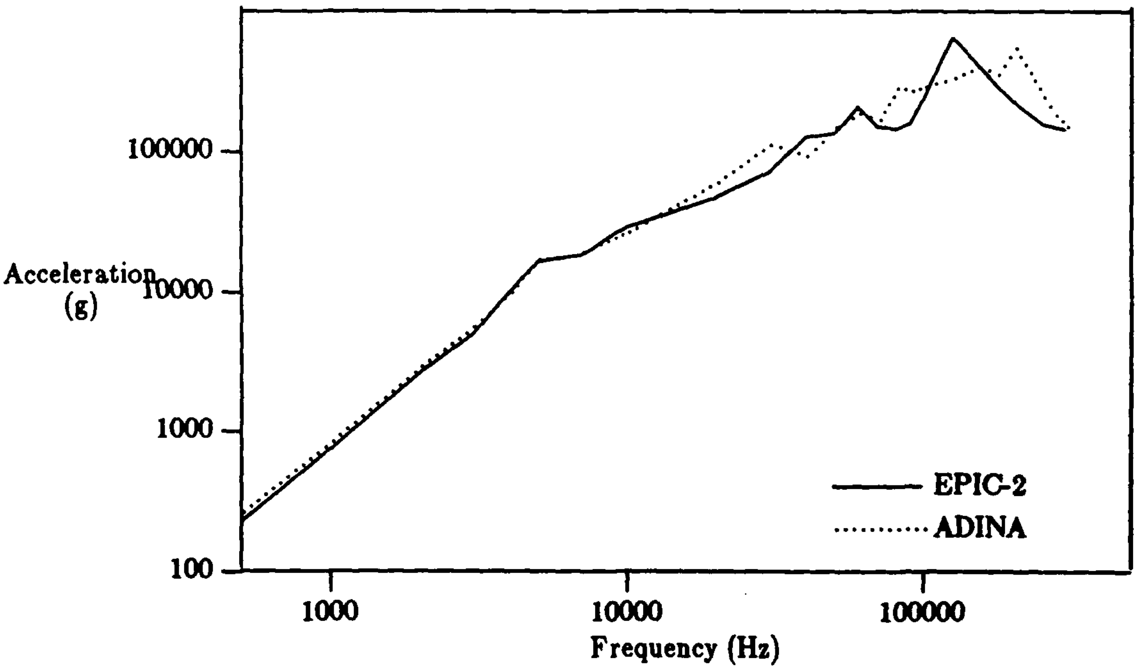

Figure 21. EPIC-2 and ADINA primary shock spectra at 244 mm for $v_p = 1012$ m/s.

IV. SUMMARY AND CONCLUSIONS

By modifying the EPIC-2 code to calculate the time rate-of-change of the target's linear momentum, the code can calculate a loading history of an impacting projectile on the target. Loading histories of 20 mm fragment simulator projectiles for two impact velocities on 38 mm x 914 mm circular rolled homogeneous armor plate have been calculated by the EPIC-2 code and have been used in ADINA finite element structural response analyses of the plate. Comparisons of EPIC-2 and ADINA response calculations show that the EPIC-2 code can calculate loading histories which do represent the loading of a target by nonperforating projectiles.

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